SECOND SEMIANNUAL STATUS REPORT

FOR PERIOD FEBRUARY 1, 1964 TO JULY 31, 1964

Required under the terms of NASA Research Grant NsG 504

"Theoretical and Experimental Investigations of Electron Density and Collision Frequency in the Lower (D and E) Regions of the Ionosphere by Research Rocket Radio Transmissions during the IQSY Using Differential Absorption, Faraday Rotation and Mass Spectrometry"

Under the direction of
D. Alpert and H. Knoebel

by

D. Skaperdas
H. Knoebel

Coordinated Science Laboratory
University of Illinois
Urbana, Illinois

June 10, 1964

ABST 29197

On April 16, 1964, the Coordinated Science Laboratory of the University of Illinois fired its first rocket at Wallops Island, Virginia, in a series of experiments conducted under a synoptic IQSY program directed by Dr. Sidney Bowhill. The experiment, which was very successful, utilized a Nike-Apache rocket and part of its 60-pound payload which was sent 105 miles into the atmosphere. The purpose of this experiment was to measure the differential absorption and Faraday rotation for the determination of electron collision frequency in the D-region. This report will describe the novel system used to make these measurements and will present the data obtained from them.

Author

The arrangements at Wallops Island were such that the CSL antenna and van, which contained all of the ground-based equipment, was located approximately two miles southwest of the rocket launching site, one mile southwest of the University of New Mexico telemetry station, and eleven miles south of the main base telemetry station. Since the experimental system contained a feedback loop closed via the CSL van, the rocket, a telemetry station and back to the van, special lines had to be laid between the van and the two telemetry stations, one of which was used as a backup. Provisions were made to close the feedback loop via whichever of the two telemetry stations obtained the better signal from the rocket. As it turned out during the rocket trajectory, the New Mexico station delivered a much better signal to the CSL van because of the shorter telephone line.

The electron collision frequency can be computed from measurements of the electron density and of the relative absorption of two oppositely circularly polarized radio waves (ordinary and extraordinary) propagated through the ionosphere. The differential absorption gives a measurement of $\int N\nu dz$ where N is the electron density, ν is the collision frequency, and z is the height. The electron density can be obtained from the relative polarization angle between the ordinary and extraordinary waves (Faraday rotation), this quantity being proportional to $\int Ndz$. The electron density can also be measured independently by means of a probe on the rocket. The relative or differential absorption and total absorptions, apart from the inverse square law attenuation, are functions of frequency. It is desirable to choose a frequency low enough to yield significant amounts of differential absorption and yet have enough extraordinary wave signal left to measure Faraday rotation. Since it is difficult to predict well in advance the level of ionospheric ionization, and since the simultaneous success of both measurements is critically dependent on the choice of frequency, provision was made for two sets of equipment tuned in advance to different frequencies in the two to four megacycles range.

Two oppositely circularly polarized waves differing by 500 cps in frequency were simultaneously transmitted from the antenna array. Looking up into the sky along the earth's magnetic field, the counter-clockwise wave is the extraordinary wave in the northern hemisphere. The two waves resolve into a plane polarized wave whose direction of polarization rotates at one-half the difference frequency, or 250 cps. A magnetic dipole receiving antenna located in the rocket receives an amplitude modulated (500 cps) signal resulting from the scan rotation of the polarization (one cycle for each half revolution). The phase of this modulation measured with respect to the beat at the transmitting antenna gives a measure of twice the apparent angular difference in polarization of the two antenna systems. This angular difference includes the integrated effect of both Faraday rotation and the physical rotation of the rocket receiving antenna due to rocket spin, which is independently measured by magnetic sensors and subtracted from the data to obtain the integrated Faraday rotation.

In the absence of differential absorption the two oppositely circularly polarized waves arrive at the rocket antenna with the same intensity and thus combine at the receiver to produce a rectified sinusoidally modulated output having sharp nulls for each 180° of scan rotation. The presence of differential absorption reduces the sharpness of these nulls so that the degree of modulation of this signal gives a measure of differential absorption while, at the same time, the phase of the modulation gives a measure of twice the Faraday rotation.

The CSL system was designed to operate in any of three modes of increasing complexity. The least complex mode maintains the transmitted ordinary and extraordinary circularly polarized waves at the same power. This method makes the measurement of Faraday rotation difficult when the differential absorption becomes large at the higher altitudes, resulting in decreased signal modulation. Furthermore, the receiver output versus input characteristics must be accurately known in order to measure the differential absorption.

The second mode is to mechanically sweep the ordinary (cw looking up) transmitted wave output power by means of an attenuator, traversing the entire range about once each second. This would insure appropriate measuring conditions at least twice each second, corresponding to data points no more than one kilometer apart.

The third and most complex mode, and the one which was used successfully on our first experiment, is to control the extraordinary wave transmitted power by means of an attenuator actuated by feedback of the received signal telemetered from the rocket, keeping the ordinary transmitted power constant. As differential absorption appears, the attenuation would be continuously reduced by a servomechanism to maintain the modulation of the received signal at a fixed 32 per cent, corresponding to a 10 db difference in the intensity of the two received wave components. The attenuator settings are continuously recorded along with the other data, enabling subsequent determination of the differential absorption.

Figure 1 is a block diagram of the entire system used for the April 16 rocket experiment. The CSL van equipment is shown within the dotted lines at the left. The two exciters X and O are crystal-controlled cw oscillators differing in frequency by 500 cps and operating just above and below 3.385 mc. Each exciter can be quickly switched to an alternate frequency in the 2-4 mc range if desired.

The output of each exciter is controlled by a waveguide-beyond-cutoff attenuator actuated in any of three ways as described above. Figure 1 indicates the mechanical system controlling the attenuators. The output shaft of each differential controls an attenuator position. The input to one differential (extraordinary) consists of a time-dependent angle $\theta_1(t)$ coming from the servomotor via a slip clutch and speed reducer, and an angular position θ_2 (power level) set manually. The output of this differential, which controls the extraordinary wave attenuator, consists of $\theta_1(t) + \theta_2$. The inputs to the second differential (ordinary) consist of the manually set angular position θ_2 (power level) and a fixed position θ_3, which is used only for calibration purposes. The output of this differential, which controls the ordinary wave attenuator, consists of $\theta_2 + \theta_3$. The voltage across a potentiometer connected to the output shaft of each differential is used to monitor the position of each attenuator. Photographs of the attenuator unit are shown in Figure 2a, b.

The outputs of the attenuators, designated as X and O, are fed into a hybrid circuit consisting of two transformers arranged to form the outputs X + O and X - O. One of the outputs, X - O, is phase shifted 90° with respect to the other by means of an extra quarter wavelength transmission line in its path. The two outputs are then amplified by the linear power amplifiers, which are commercial one kilowatt transmitters made by the Technical Materiel Corporation, and then fed to the appropriate antenna array. Each array consists of four horizontal half-wave dipoles elevated one quarter wavelength above the ground plane and arranged as the sides of a square, with the inputs of the opposite pairs fed in phase, one pair being fed by $(O + X)\angle 0^{\circ}$, the other by $(O - X)\angle -90^{\circ}$. The combined space and time quadrature results in two oppositely circularly polarized waves, X and O, which would degenerate to a simple linearly polarized wave if X and O were at the same frequency. The difference of 500 cps between X and O results, instead, in a linearly polarized wave in which the plane of polarization rotates at 250 cps. Each dipole pair, moreover, gives an antenna gain over a single dipole of 4 db, and the presence of the imperfect ground plane increases the gain by perhaps another few db. In order to test the antenna array, a horizontal ferrite rod antenna, placed at the center of the array and rotating at 600 rpm, is provided. If during tests the transmitting antenna array transmits anything but a circularly polarized wave, it is easily seen by this rotating antenna as a modulated rf signal.

The ferrite-rod antenna (see Figure 3a, b) located in the Nike-Apache rocket gives an rf signal output which is amplitude modulated in the region of 500 cps which is twice the 250 cps rotation of the transmitted plane of polarization plus the rotation of the rocket spin and a small contribution from Faraday rotation. The rocket spin is independently measured by a Geophysics Corporation of America magnetic aspect sensor contained in the payload.

The output of the antenna is fed to a transistorized, crystal-controlled superheterodyne receiver designed and developed by Space Craft, Inc. (see Figure 4). The sensitivity of the receiver for a 10 db signal-to-noise ratio and a signal which is 90 per cent modulated at 500 cps is -120 dbm or better. Its dynamic range is from threshold to -60 dbm with no more than 6 db change in output level. The receiver bandwidth is about 2 Kc and the AGC time constant for the first payload was about 100 msec. The modulated rf signal is detected, DC coupled and amplified to a 5 volt level for feeding a standard telemetry sub-carrier oscillator and telemetry transmitter.

The telemetry signal from the rocket is received and recorded at the main base and New Mexico telemetry stations. Both stations re-transmit the telemetered receiver signal, which contains the 500 cps difference frequency and a DC component, to the CSL van via telephone lines where both are monitored. The better of the two signals is fed to a circuit which separates the AC and DC components and compares their relative magnitudes as a measure of the per cent modulation. If this modulation is different from a predetermined value of 32 per cent, a DC error signal of appropriate polarity is developed. This is chopped at 60 cps, amplified and fed to a servomotor. The servomotor then controls the relative position of the extraordinary wave attenuator (X) in order to maintain a constant 32 per cent modulation at the rocket receiver. A tachometer is incorporated to stabilize the feedback loop.

Signals generated at the transmitter van and sent to the telemetry stations for recording are the 500 cps beat frequency of the two exciters used as a reference and the two attenuator position signals. Additional signals recorded at the telemetry stations of interest to this experiment include the telemetered rocket receiver signal, which is sent back to the van for closing the servo loop, the telemetered magnetic aspect sensor signal, the universal timing signal and the rocket trajectory data obtained from the MIT radar tracking site. In addition, part of the 500 cps reference frequency is added to the receiver signal and part is phase shifted 90° and added to the receiver signal and both recorded. These are used as an alternative way of extracting the Faraday rotation data.

The Nike-Apache rocket used in CSL's first experiment, designated as Number 14.143, reached an apogee of 105 statute miles and a horizontal range of 110 miles with a flight time of 406 seconds. All of the differential absorption and Faraday rotation during the ascent took place from about 60 sec to 90 seconds after launch. Apogee occurred at 205 seconds.

A general picture of the experiment can be seen in Figure 5 which shows five recorded signals of interest during the entire rocket flight. The signals at the top and bottom edges are universal time signals. The second signal from the top is the telemetered rocket receiver output consisting of a DC component and the 500 cps difference frequency, modified by the rocket spin frequency and Faraday rotation.

The next lower signal is the telemetered magnetic aspect sensor which measures the transverse component of earth's magnetic field. Each period of this sinusoidal signal represents one rotation of the rocket. The next lower signal represents the magnitude of the extraordinary wave transmitted power. It consists of a 200 cps audio signal output of a linear potentiometer coupled to the servo-controlled attenuator. The second signal from the bottom represents the magnitude of the ordinary wave transmitted power as indicated by the amplitude of a 100 cps audio signal. The distance between vertical lines represents one second of time. It is seen from Figure 5 that the ordinary wave power was kept constant (at about 10 watts) during the entire flight. The initial extraordinary wave power was at about 1 watt. Time of launch (t = 0 sec) can easily be discerned from the magnetic aspect sensor signal, as the rocket begins to spin at an increasing rate. No particular effect is observed at t = 3.5 sec where the Nike first stage burned out. However, at about t = 20 sec, when the second stage (Apache) fired, a slowdown of the rocket spin occurred, a usual phenomena which cannot be explained by the Wallops Island personnel. At t = 28 sec, the Apache stage burned out and a precession of the rocket about its spin axis appears. At t = 40 the ejectable doors covering apertures used in a separate radiation experiment conducted by Geophysics Corporation of America were released. The rocket precession damped out at about 70 sec, at which time the rocket spin rate stabilized at 6 rps. Apogee occurred at 205 sec and at t = 330 sec the rocket appears to have re-entered the earth's atmosphere at a point where frictional drag caused it to tip over and descent like a precessing bomb. At t = 340 seconds the magnetic aspect sensor axis was perpendicular to the earth's magnetic field, resulting in zero signal output. At t = 406 the rocket hit the ocean, resulting in loss of signal.

Returning to the other signals, at -60 sec < t < 0 sec, the servo loop was closed, with attenuator X at 32 db below one kilowatt and attenuator O at 20 db below one kilowatt. At t = 0, there was a sudden change of the rocket receiver signal, causing a servo impulse which quickly damped out, probably due to the rocket blast. Figure 6a is a time enlarged view of this event. In these figures, one second of time is represented by the light vertical lines (see Figure 6b). In Figure 6 are also shown, as the second and third records from the top, the sum of the rocket receiver signal (fourth from top) with the 500 cps reference signal and with the 500 cps reference signal phase shifted 90°. These traces, together with the magnetic aspect sensor trace (fifth from top), are used to measure Faraday rotation. In Figure 6a the rocket has not yet made one revolution. At t = 28 to 40 sec the rocket receiver was cut off in order to obtain a calibration signal. The signal in this interval represents zero DC receiver output voltage. In the interval t = 60 to 90 seconds, the output of attenuator X is increasing, showing that differential absorption is taking place. Figure 6b is representative of the recorded signals near t = 66 sec, where the rocket is at an altitude of 77 km. The magnetic aspect sensor trace indicates that the rocket was spinning at about 6 cps. The rocket receiver difference frequency shows a modulation due to the rocket spin and standing wave caused by reflection of the extraordinary wave at a higher altitude. At t = 85 sec (100 km), Figure 6c shows the standing wave ratio getting larger. At t = 90 sec (106 km), the differential absorption (and Faraday rotation) suddenly stop, signifying a reflection of the extraordinary wave at this point. A further time expansion of Figure 6d shows a sudden phase reversal of the receiver difference frequency, corroborating this reflection. At this altitude the maximum system resolution between clockwise and counterclockwise circularly polarized waves has been reached (about 26 db). Above this altitude only the standing waves are of interest. Figure 6e shows the rocket receiver modulated by the standing wave at t = 110 sec (125 km). The receiver difference frequency in this case is due to some ordinary (cw) component being radiated at the extraordinary frequency due to a slightly elliptically polarized antenna system. It is interesting to note that at all altitudes higher than the extraordinary reflection level (106 km), the receiver difference frequency suddenly dropped to the value of 500 cps, the value it had before launch. This can be explained if the two circularly polarized waves are rotating in the same sense (cw in this case), thereby nullifying the effect of rocket spin.

A comparison of the standing wavelengths in Figures 6b and 6d shows the effect of the decreasing index of refraction and consequent increasing phase velocity of propagation with increasing altitude. At t = 120 sec (134 km), a zero beat of the rocket receiver modulation envelope caused by the rocket spin and the standing wave pattern is clearly seen in Figure 5. The effect of a very large standing wave ratio on the rocket receiver output is shown in Figure 6f at t = 141 sec (149 km). Since the AGC feedback loop has an integrator at the standing wave frequency, the receiver closed loop differentiates the standing wave pattern (full wave rectified sine wave) to give the waveform shown in Figure 6f. At t = 147 sec (152 km), a second reflection layer occurs. In Figure 6g it is seen that the rocket receiver signal suddenly becomes noisy. One second later the second calibration signal occurred for a total of 12 sec, masking the presence of a third reflection layer. At this point the system servo loop was opened. During the descent the combination of a large standing wave ratio and rocket precession and tilt made the data extremely noisy. However, at t = 263 sec (153 km) the rocket again broke through the third reflection level (Figure 6h). The system servo loop was again closed a few seconds later as seen by the jittering attenuator X record. The second reflection level with identical rocket receiver characteristics as in Figure 6g was again passed at t = 281 sec (142 km). At this time, attenuator X jumped to a new level and stayed there until the differential absorption region starting at t = 325 sec (102 km) was reached, at which point the extraordinary power started to decrease. Nine seconds later, the rocket started to tumble, hitting the ocean at t = 406 sec. At this point the system servo loop was broken and the two attenuators were driven against their stops, as shown in Figure 5.

The differential absorption and Faraday rotation versus altitude is shown in Figure 7. A total differential absorption of about 20 db and a Faraday rotation of about 14 cycles was observed. The Faraday rotation data was obtained by three different methods of data analysis, the results closely agreeing. One method was fully automated, using CSL's recording tape of the flight data and two phase meters, with the Faraday rotation versus time of flight indicated on a pen recorder. A second method consisted of manually counting the total number of cycles of the rocket receiver difference frequency, up to a given time, and subtracting from it the total number of cycles of the 500 cps phase reference and the rocket spin frequency up to that same time. The third method consisted of counting the number of cycles of the modulation envelope of the second or third traces from the top in Figure 6 up to a given point and subtracting the total number of cycles of the rocket spin frequency up to that same point.

The probable error for measuring Faraday rotation by the latter two methods is about 0.1 cycle. However, the probable error of the first method is about five degrees at the low values, increasing as the rate of rotation increases. The probable error in the differential absorption method is about 0.5 db due to the noise pickup on the attenuator X and O data lines.

The computations for collision frequency are currently being done under Professor Sidney Bowhill's direction.

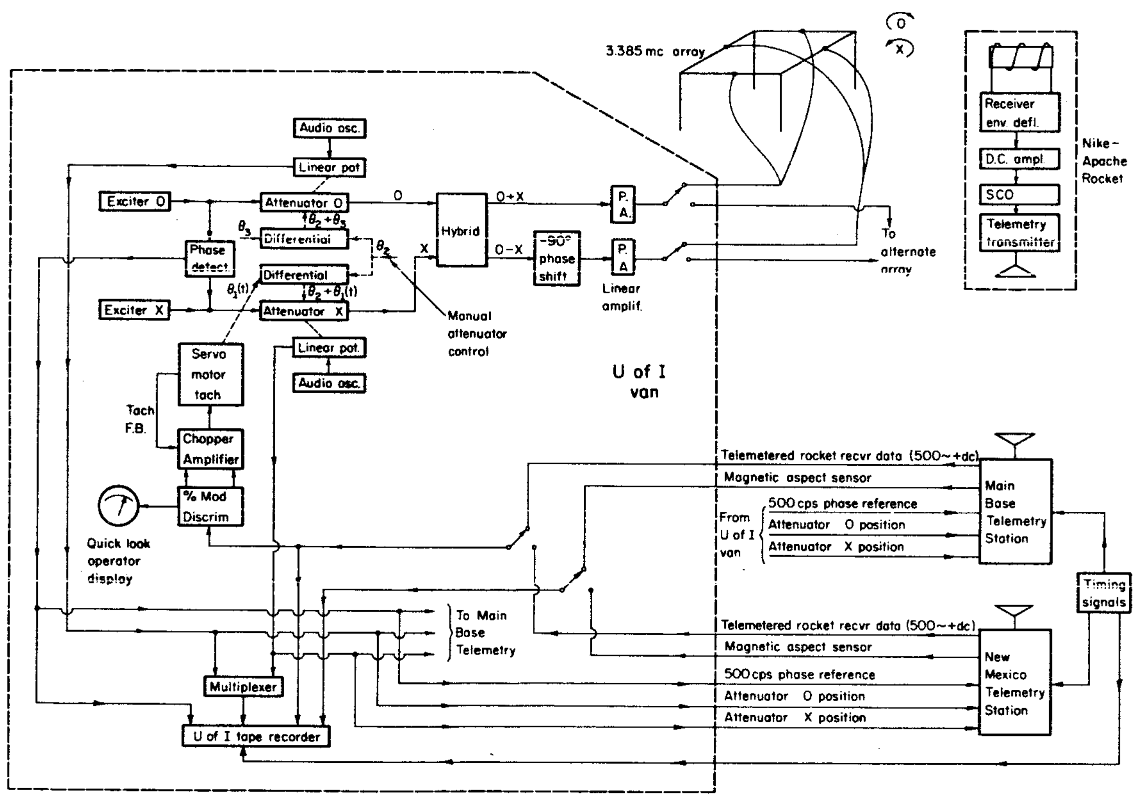
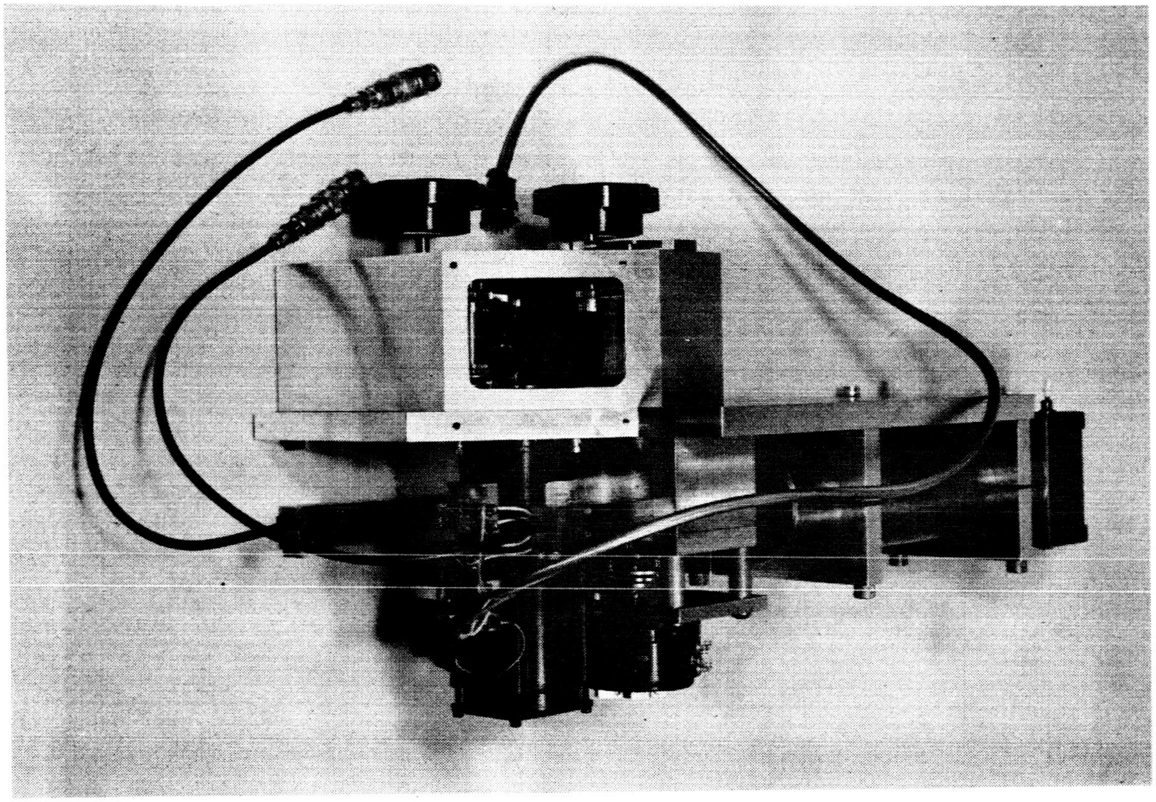


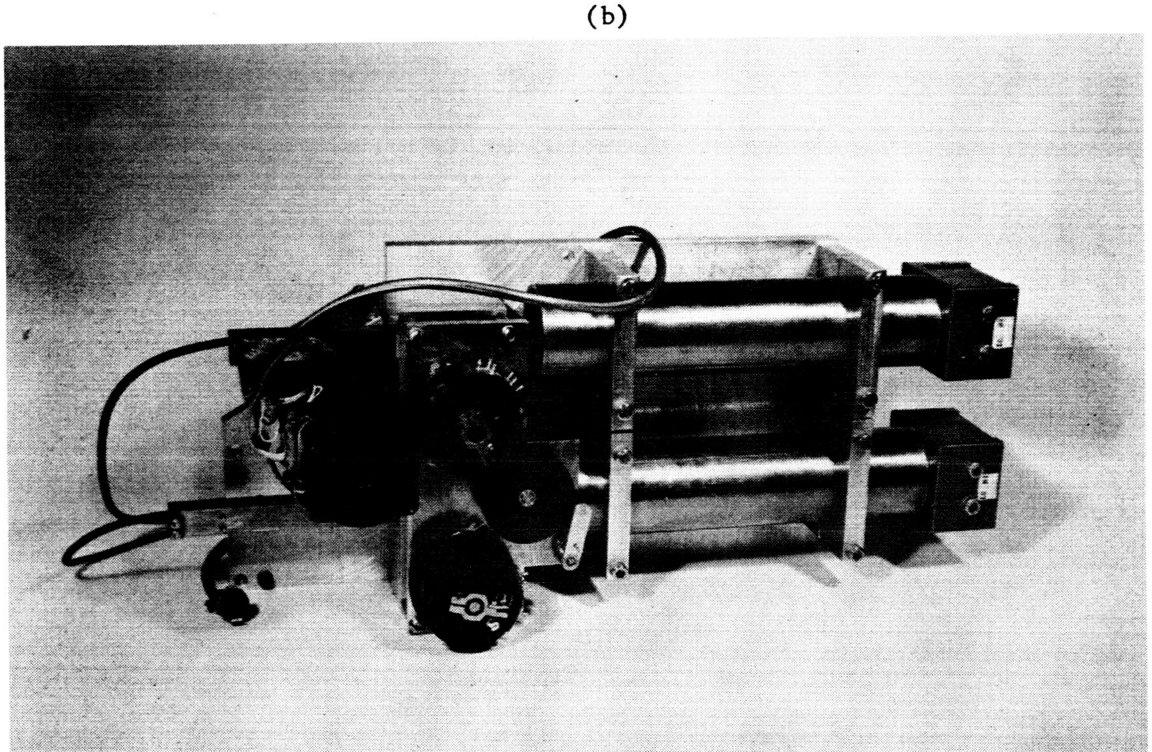
Figure 1. Schematic of CSL Ionosphere Rocket Experiment.

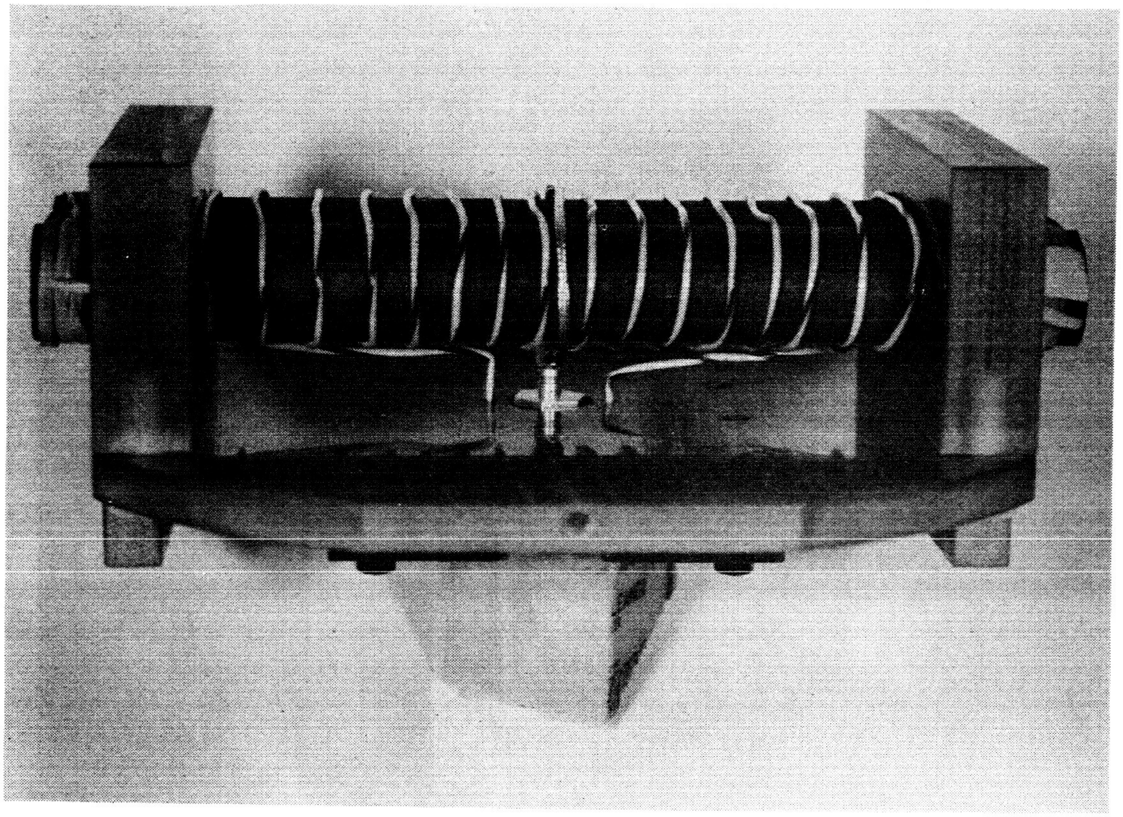


(a)

Figure 2. Attenuators and Servo Drive Mechanism.

(b)

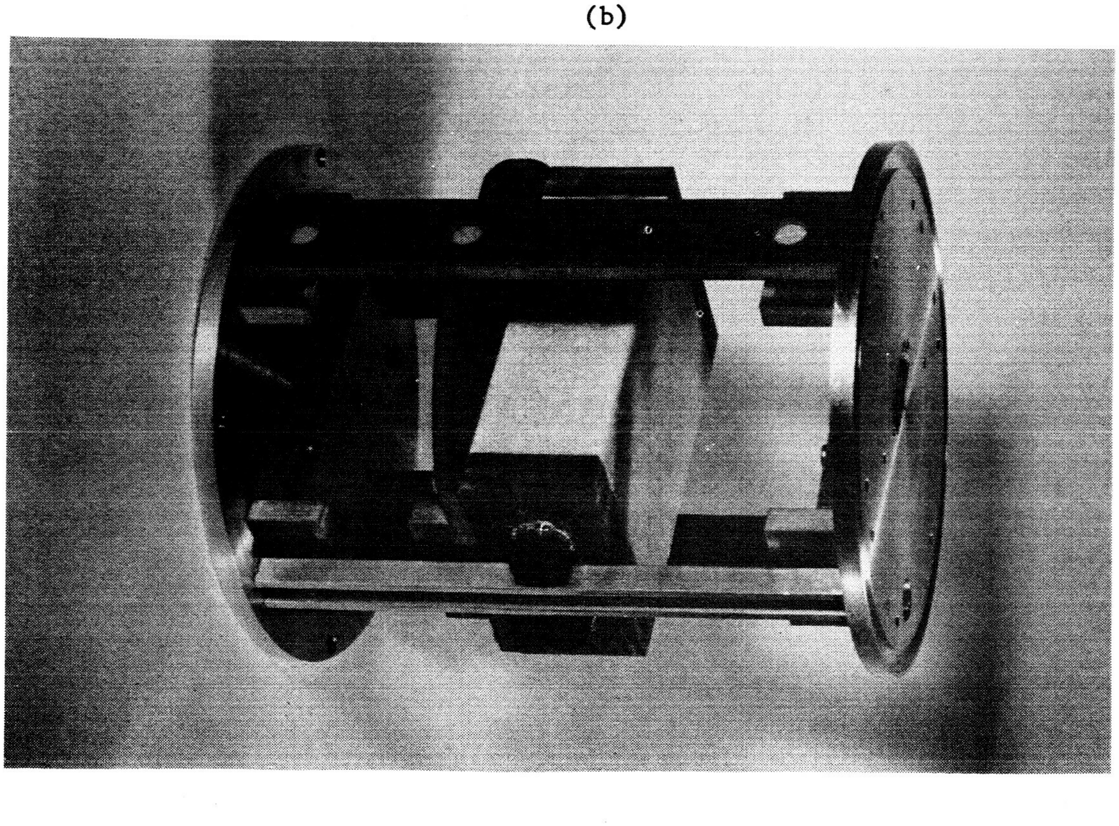




(a)

Figure 3. Ferrite-rod Rocket Antenna.

(b)



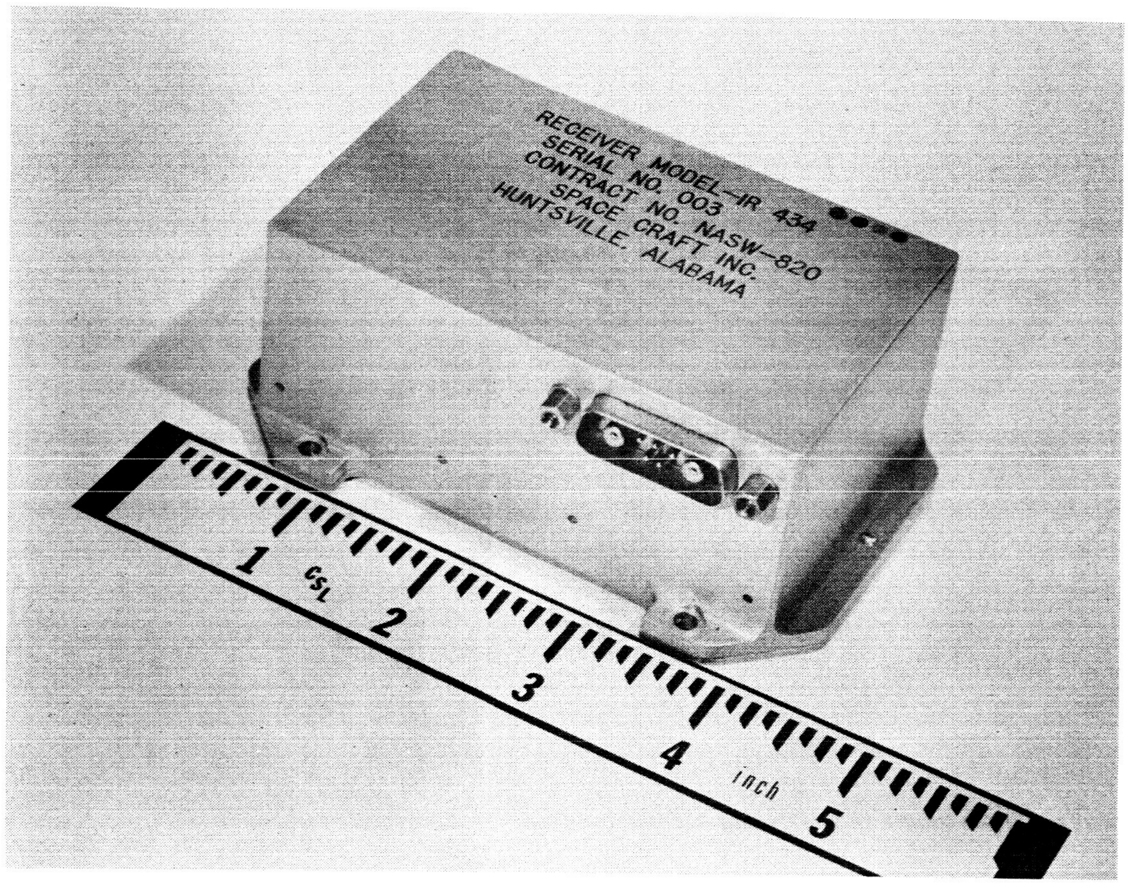
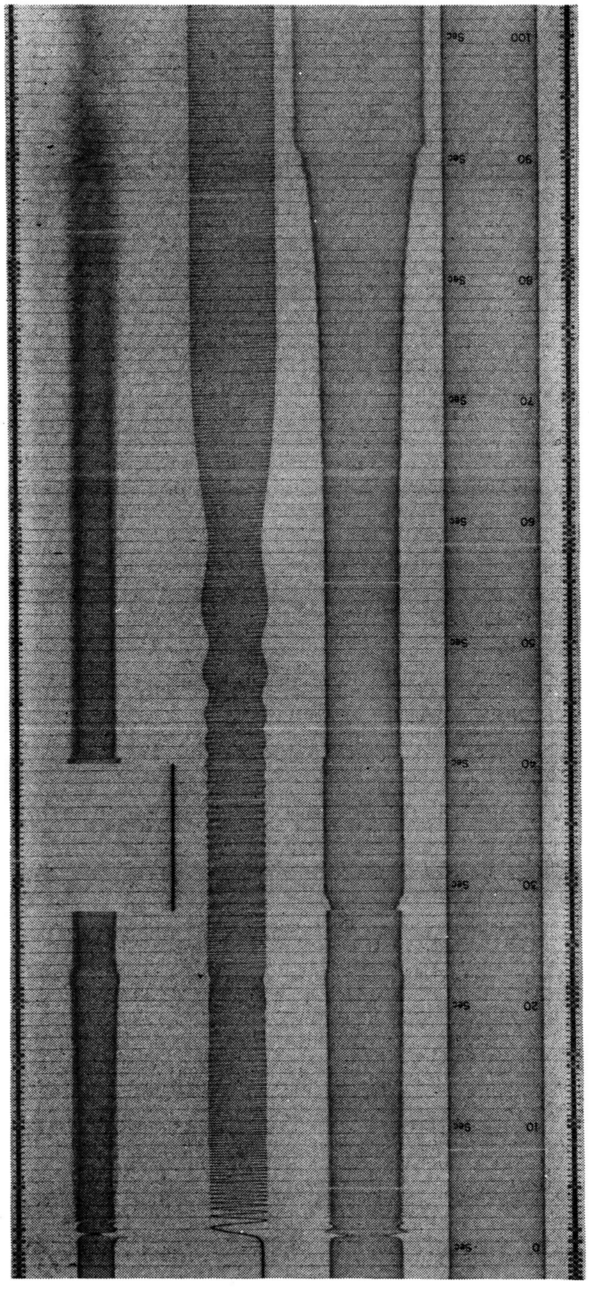
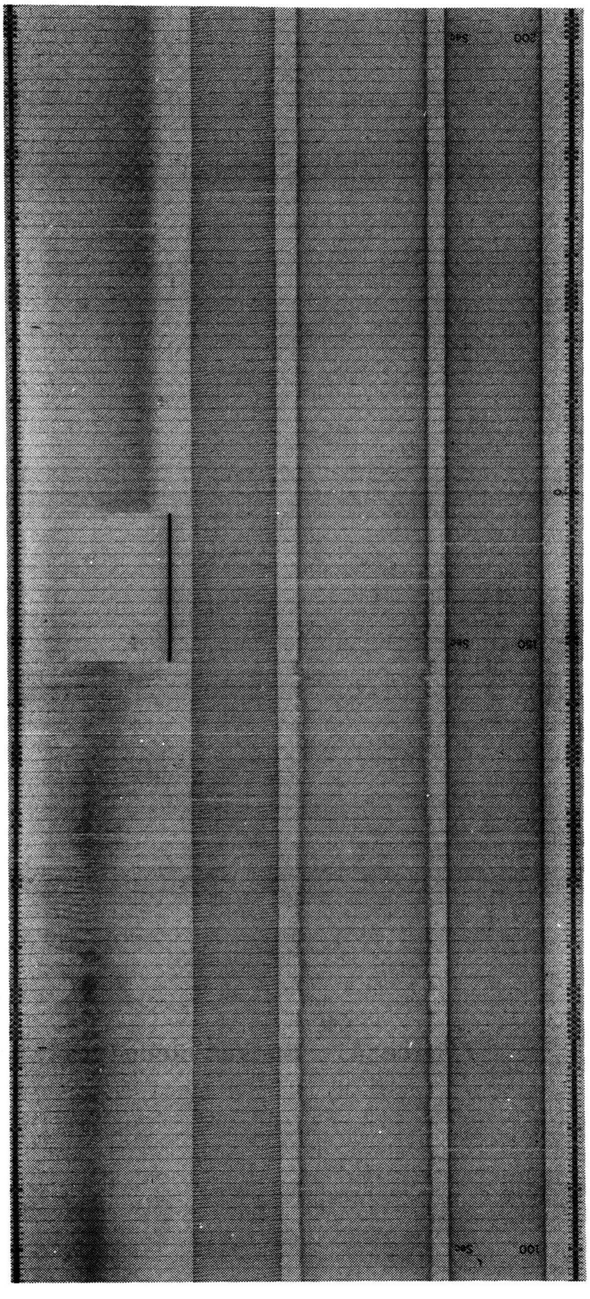


Figure 4. Rocket Receiver.





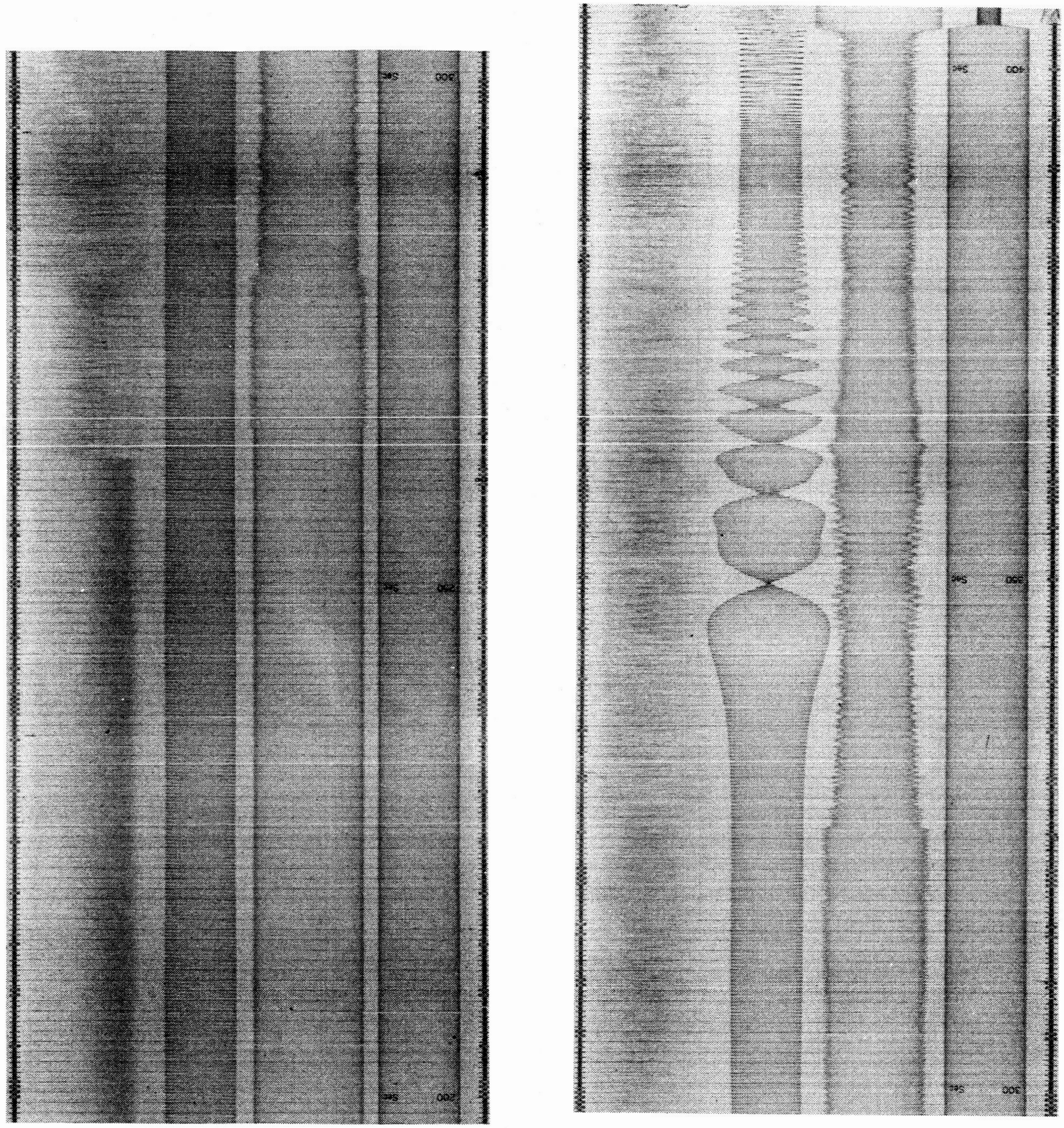
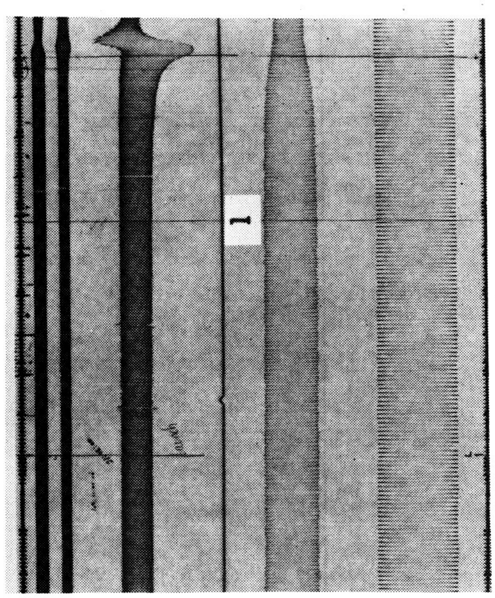
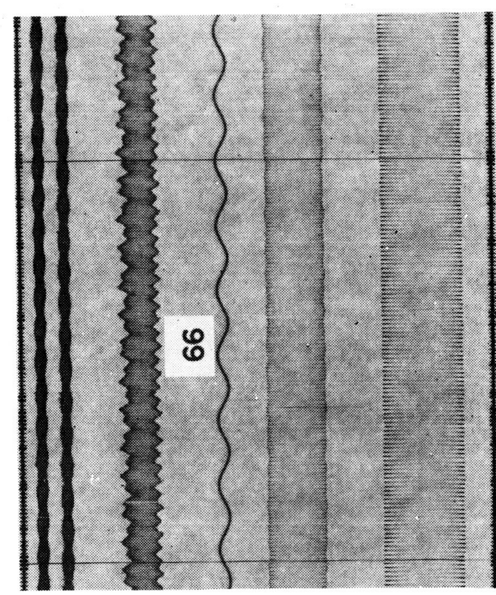


Figure 5. Rocket Flight 14.143. Recorded Signals.

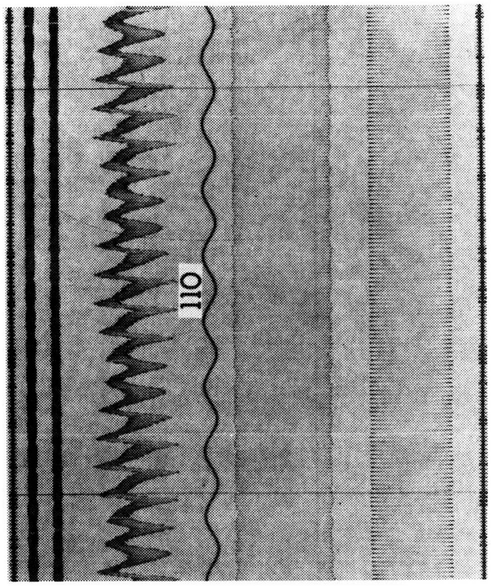
19a



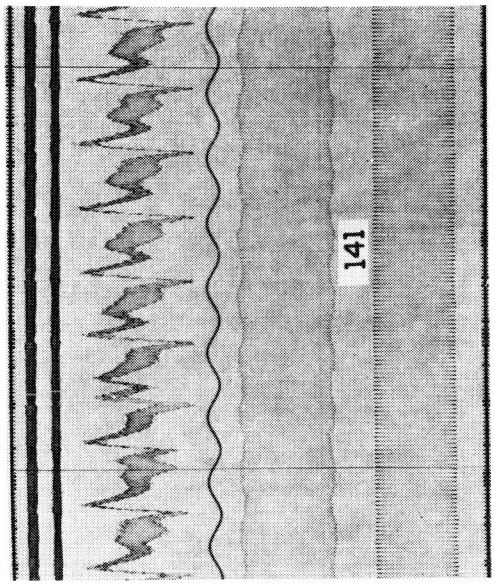
a



b



e



f

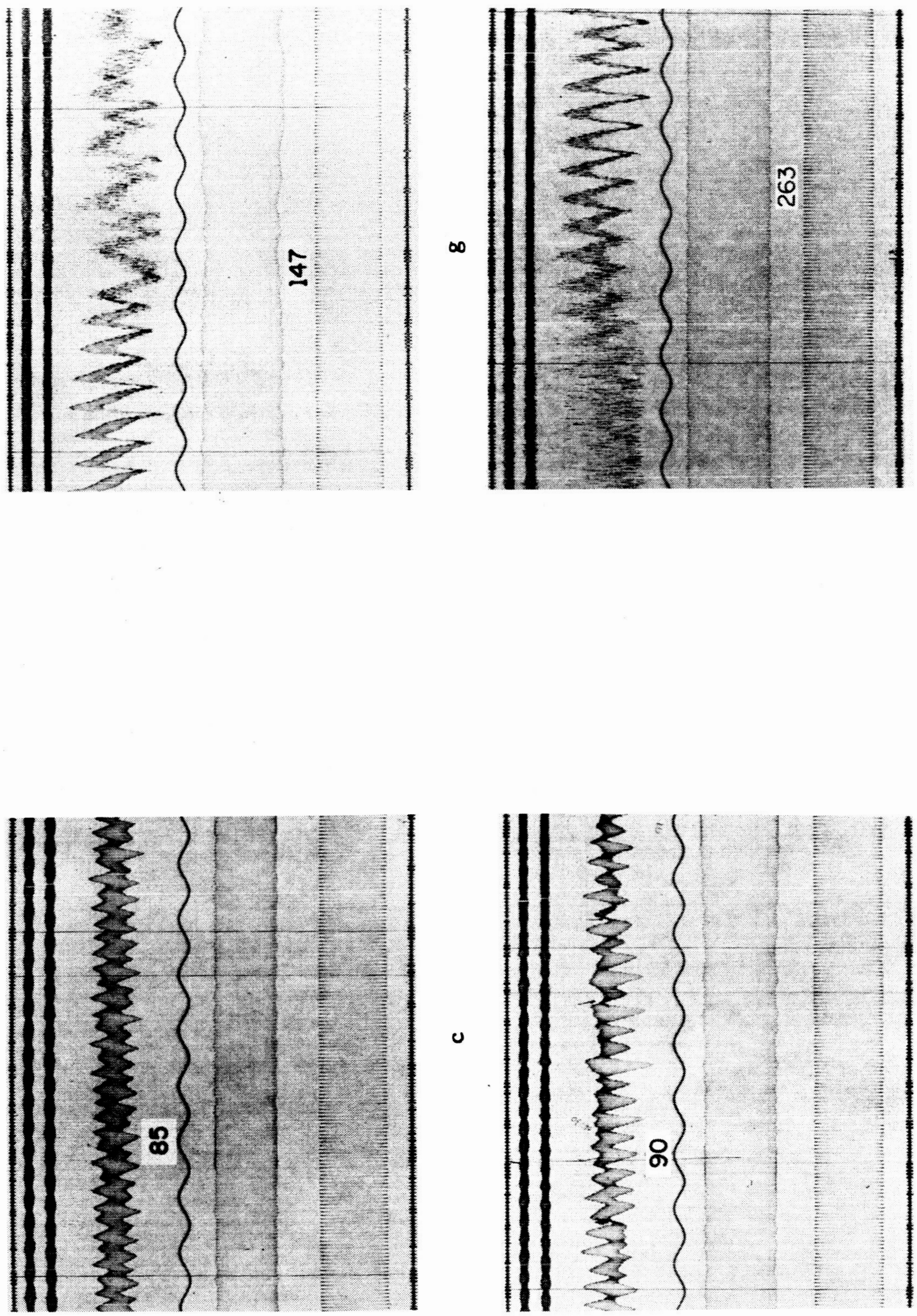


Figure 6. Expanded Views of Portions of Figure 5.

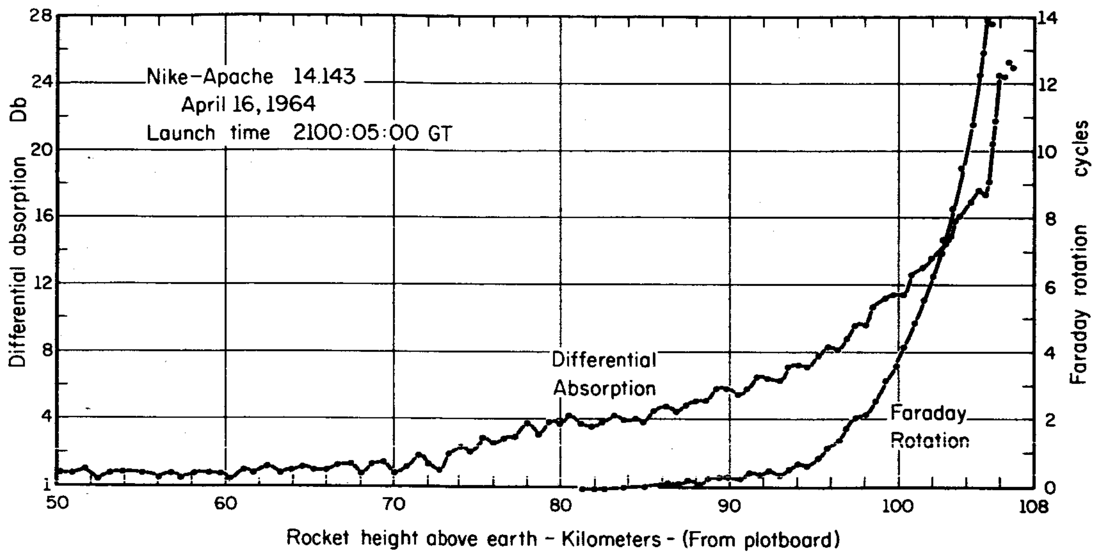


Figure 7. Differential Absorption and Faraday Rotation versus Rocket Height.